

Second Substitute Specification 09/827,462

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METHOD FOR PRODUCING CUTTING TOOLS

CROSS-REFERENCE TO RELATED APPLICATION

This is a divisional of application number 09/253,212 filed February 19, 1999 and now U.S. Patent 6,241,431, which claimed priority from European Patent application number 99 103093.3 file February 17, 1999.

FIELD AND BACKGROUND OF THE INVENTION

Definitions

In the present specification hard material means a compound, namely a carbide, oxide, oxycarbide, but in particular a nitride, nitrocarbide, oxynitride or nitrooxycarbide, of at least two of the metallic elements listed in the following, in particular of Ti and Al. Metallic elements means Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W and Al.

If within the scope of the present application reference is made to a change of the composition of the hard material layer material in the active edge region, this means a difference of at least 2 at% of a hard material layer metal component between a hard material layer in the active edge region and a hard material

layer in the remaining regions of the tool.

Analogously, no change exists if the stated difference is less than 2 at%, in particular less than 1 at%.

Machining cross section f_a means the product "Vorschub x Schnitttiefe" {Advance x cutting depth} according to DIN 6580, Section 11.1.1, "Bewegungen und Geometrie des Zerspanungsvorgang" [Motions and Geometry of the Machining Process] (DN 6580, Oct. 1985).

German Patent DE 38 25 399 as well as European Patent EP 0 352 545 disclose coating tools by means of a vacuum process with a layer of hard material, and therein especially with a (Ti,Al)N hard material layer. The coating takes place such that in the active edge region, i.e. in the region of the cutting edges, the hard material layer material has a changed composition compared with that on the remaining tool regions: according to DE 38 25 399 as well as EP 0 352 545 at the active edge regions of drills a thinning out of the aluminum is realized which is distinguishable on the tools by the reddish or yellowish coloration of these regions. Thinning-out ratios of 5 at% or 2 percent by mass of the Al are declared.

SUMMARY OF THE INVENTION

The process discovered, namely to change the hard material layer composition in the active edge region, is fundamentally represented as a measure for attaining a significant improvement of the quality of the coating.

The invention starts from the understanding that generally, tools have a hard material layer in their active edge region which is substantially, and within the scope of measurability, an unchanged material composition. In contrast, the composition of the hard material layer in the active edge region is changed relative to the hard material layer composition on the remaining tool regions according to the present invention. The invention proposes a process for the protective coating of machining tools as well as a set of at least two tools, by means of which substantially improved specific working properties are attained. In particular, working properties such as the service life of the tool or decrease of the tool wear, are improved.

According to the process of the invention, a hard material layer is applied onto the basic tool body but is selected for the specific stress the tool is meant to endure. The composition of the hard material layer in the active edge region is either left with minimum changes relative to the composition of the hard material layer in the remaining coating regions on the tool basic body or is intentionally changed. The former, i.e. constant composition, is realized if the primary requirements to be made of the tools relate to adhesive strength of the hard material layer and only secondarily to hardness of the hard material layer. The second, in contrast, is realized if the primary requirements to be made of the tools relate to hardness of the hard material layer and only secondarily to adhesive strength of the hard material layer.

According to the invention it was found that by changing or not changing the compositions of the hard material layers in the

active edge regions as a function of the working purpose of the tools, that is, by either providing a hard material coating of constant composition or a hard material coating of varying composition in the active edge region, critical improvements were realized. If tools for given applications, are coated with the wrong coating technique of the two mentioned, often an impairment of the tools' working properties, in particular tool life, results.

It could be shown, for example, that according to EP 0 352 545 with a thinning-out of the coating only in a few fields of machining, better or at least equally good results can be achieved, compared to the application of corresponding tools with a lower or no, at least not measurable, difference in the concentration of the hard material layer. It should be pointed out, in particular, that the example mentioned in EP 0 352 545 with respect to service life of twist drills, based on the representative comparisons made according to the present invention, is erroneous in the case where two completely identical, except for stated coating difference, and identically coated drills are present. The phrase completely identical here means an application of the same coating processes, in particular arc or sputtering processes, on identical tool bodies, and the adjustment of the realized or not realized concentration difference exclusively by adjusting the voltage applied on the basic tool body during the coating with respect to ground or reference potential, referred to as bias voltage U_{bias} in the following, and/or of the reactive gas partial pressure $p_{reactiv}$ in the vacuum coating receptacle with further process parameters remaining unchanged.

It can be seen that the prior known thinning-out in the active edge region can effect critical disadvantages in the use of the tool, and that consequently it is necessary to assess very carefully according to the invention, which process is applied at which time, for example, by the fact that precisely the aluminum depletion of the hard material layer in the active edge region has negative effects on wear through thermal stress of the hard material layer since through the aluminum thinning-out potentially, now less aluminum reaches the surface of the hard material layer through diffusion and no continuous thermally insulating aluminum oxide layer can be formed there. The Al_2O_3 layer on the surface is simultaneously worn out during the working process and formed again through Al diffusion. But precisely this phenomenon can critically influence the durability of the hard material layer with aluminum component under specific conditions.

According to the invention as explained in the following examples, it could be shown that tools with a hard material layer, in particular a (Ti,Al)N layer, comprising only a low or no longer measurable composition change of the material of the hard material layer in the active edge region, in many applications yield a substantially better service life, even with increased cutting efficiency, than other tools that are otherwise identical, with a composition change of the hard material layer in the active edge region. Especially good results can be achieved, in the case given first, if, in the active edge region, the change of one of the metal components of the hard material layer is less than 2 at%, preferably it is maximally 1 at% or no longer measurable.

Following another feature of the invention, when using arc vaporization for depositing the hard material layer, an as much as possible unchanged hard material layer composition in the active edge region is attained when the ratio U_{BIAS} - of the electric basic tool body voltage relative to reference potential, usually ground potential - to the partial pressure of the reactive gas $p_{reactiv}$, has the following range of values:

$$1 \times 10^{-3} \leq U_{BIAS}/p_{reactiv} \leq 4 \times 10^3,$$

with the unit of voltage being "volt" and the unit of pressure "mbar".

Furthermore the invention produces drills, roughing milling cutters, peripheral milling cutters and hobbing machines with as much as possible unchanged composition of the hard material layer in the active edge region, and front-end milling cutters and ball-end milling cutters with changed composition of the hard material layer in the active edge region.

It was in particular found that the composition of the hard material layer in the active edge region of the tools should be unchanged, as far as possible, if these tools are intended for the working of relatively large voltage or cross sections and for low cutting rates; however, tools should be prepared with a changed composition of the hard material layer in the active edge region if the tools are intended for relatively low voltage machining cross sections but relatively high cutting rates.

A further criterion for making the selection according to the invention, of the type of hard material coating in the active edge region of the tools, is for the working of materials with a

hardness of at most 45 Rockwell (HRS) and a tensile strength up to at most 1500 N/mm², preferred for the working of heat-treatable steels, high-alloy and stainless steels as well as of nonferrous metals, to carry out the coating with hard material in the active edge region as much as possible without changing the composition. The same applies to tools whose active edges in use are simultaneously subjected to different cutting rates, such as in particular, drills on which a minimum cutting rate occurs at the tip of the drill and a high rate on the drill periphery.

Basic tool bodies are coated in the active edge region with changed composition of the hard material layer, which are intended for the machining working of materials with a hardness of more than 45 Rockwell (HRC) and with a tensile strength of more than 1500 N/mm², in particular for operations involving the removal of hard metal by cutting tools, for example, instead of grinding or erosion processes.

In the following AISI refers to known materials categorized by the American Iron and Steel Institute and DIN refers to materials categorized by the Deutsches Institut für Normung (German Standards Institute). Other known standards are also used to identify other material types.

It has in particular been found, that

- indexable inserts for turning tools and for materials AISI 304SS or DIN 1.4306 to be worked,
- indexable inserts for peripheral milling cutters for

materials AISI 4140 or DIN 1.7225 to be worked,

- indexable inserts SEE 42TN for milling cutters for material SKD 61 (HRC 45) to be worked,
- hard metal roughing shank-type milling cutters for materials DIN 1.2344 to be worked in dry working, as well as
- HSS drills for materials AISI D3 or DIN 1.2080 as well as GG 25 to be worked with emulsion lubrication

should be realized as much as possible with unchanged composition of the hard material layer in the active edge region; however

- hard metal roughing shank-type milling cutters for materials DIN 1.2311 to be worked with emulsion lubrication
- hard metal front-end milling cutters for materials AISI D2 or DIN 1.237 to be worked
- hard metal ball-end milling cutters J97 for dry working of DIN 1.2343, 49.5 HRC, preferably with changed composition of the hard material layer in the active edge region.

Further, at least two tools are therein provided, one for a first specific application operation in which primarily high

adhesion strength of the hard material layer is required, however, only secondarily high hardness of the hard material layer, and a second tool, during the application of which primarily high hardness of the hard material layer is required and only secondarily high adhesion strength of this layer.

In this tool set according to the invention, the first tool is coated in the active edge region with substantially uniform composition of the hard material layer, however the second one with varying composition of the hard material layer.

Whether or not a tool is provided with a hard material coating whose composition in the active edge region is changed, is often evident by the coating coloration of the tool in the active edge region, thus typically for (Ti,Al)N layers with Al depletion in the active edge region through its yellowish or reddish coloration in stated region.

Through the present specification and the claims, the relevant expert gains clear instructions, based on which criteria he is to investigate, which active edge hard material coating techniques lead to better tool application behavior. Even when in specification and claims specific tool types as well as their type of application and the materials to be worked are specified, this is not to be understood to be conclusive for the expert but rather he recognizes, based on the evaluation of the useful coating type for further tools for further application fields and materials, considered by analogy, which coating technique is to be applied, or he obtains the advice first of all to try which of the two coating techniques leads to better results.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be explained with reference to examples and, in connection therewith, to the drawing, wherein:

- Fig. 1 is an Auger line scan diagram, recorded in the active edge region, by example of an indexable insert of type SNGA 120408, at right angles to the active edge, the titanium and aluminum distribution being recognizably uniform, corresponding to an unchanged composition of the hard material layer in the active edge region;
- Fig. 2 is an Auger line scan diagram recorded on the same object as in Figure 1, however, on which the titanium and aluminum distribution in the active edge region is of changed composition of the material of the hard material layer; and
- Fig. 3 is a simplified and schematically diagram of a view onto an installation used for the described experiments.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the discussed examples, identical basic tool bodies were in each instance coated by means of arc vaporization. In examples 1 to 4 the coating conditions specified in the following by A and B were selected. The layer thickness, in particular in the active edge region, was approximately 3.5 μm .

The coatings realized under A show a uniform titanium or aluminum distribution according to the Auger line scan of Figure 1. It was recorded starting on the edge of an indexable insert of Type SNGA 120408 coated according to A at right angles to the active edge or the polished machining face to a length of 0.5 mm, corresponding to approximately 60 measuring points per scan. The hardness of the layers realized under A was approximately 3000 HV_{0.05}.

The parameters described under B yield layers which in the active edge region (that is on either side of the edge proper) and have a strong depletion of the aluminum, namely from 50 at% (on the edge) to 40 at%, or an enrichment of titanium from 50 at% (on the edge) to 60 at%, according to Figure 2. With more sharply pronounced edges, such as for example in the case of knife cutters, markedly greater differences in the material composition of the hard layer could be measured. The hardness of the layers deposited under B is approximately 3500 HV_{0.05}. In the following tables, the two parameter sets A and B for the arc vaporization coating are summarized.

All experiments were carried out on an installation BAJ 1200 under production conditions.

In Figure 3 the view onto an installation of the given type is shown schematically. In a cylindrical treatment chamber 1 a revolving table is supported rotatably with respect to the central axis A₁ as shown with the rotational motion ω_1 . On the revolving table several substrate carrier arrangements 3 are supported each rotatable about axes A₂, as is shown with the

rotational motion ω_2 . On the substrate carrier arrangements 3 are supported in individual substrate carriers the substrates 5 grouped about the particular axis A_2 , which substrates are preferably themselves, and as shown with ω_3 driven about their own axis, set into rotational motion.

Onto the wall of the chamber 1 are flanged one or several arc vaporizer sources 7. With respect to the specific and detailed structure of the installation used, reference is made for example to US A 5 709 784 by the same applicant.

In the experiments exclusively N_2 gas was used, i.e. as the working gas as well as also the reactive gas. It is understood that additionally also an inert gas, in particular argon, can be used as the working gas. For the coating of type A the total pressure, i.e. the N_2 pressure, was approximately 3×10^{-2} mbars, for the experiments B approximately 1×10^{-2} mbars.

Ti, Al was arc-vaporized from alloy targets.

In the following tables denote further:

p_{N_2} : partial pressure of reactive gas N_2

I_{Ti} : arc current during titanium vaporization

I_{TiAl} : arc current during TiAl alloy vaporization

Coating Parameters A:

Parameter	TiN Intermediate Layer	(TiAl)N Hard Material Layer
P_{N_2} [mbar]	8×10^{-3}	3.2×10^{-2}
I_{Ti} [A]	170	0
I_{TiAl} [A]	0	200
U_{BIAS} [V]	-200	-40

Coating Parameters B:

Parameter	TiN Intermediate Layer	(TiAl)N Hard Material Layer
P_{N_2} [mbar]	8×10^{-3}	1×10^{-2}
I_{Ti} [A]	170	0
I_{TiAl} [A]	0	200
U_{BIAS} [V]	-150	-150

In all cases a TiN intermediate layer was installed between basic tool body and hard material layer.

Example 1

Tool : Turning tools with indexable insert K313/CNGP432
 Material worked : AISI 304SS \approx DIN 1.4306
 Cutting rate : $v_c = 244$ m/min
 Advance per rotation : $f_u = 0.2$ mm/r
 Cutting depth : $a_p = 1.524$ mm
 Lubricant : emulsion

Experiment No.	Layer	Working Cycles	Cycle Average
1	TiN	7.5	6.8
2		6.5	
3		6.5	
4	TiAlN "A"	21.0	18.3
5		17.0	
6		17.0	
7	TiAlN "B"	6.4	5.8
8		5.5	
9		5.5	

Example 2

Tool : Peripheral milling cutters with indexable insert
K903/SEHW43A6T

Material worked : AISI 4140 = DIN 1.7225

Cutting rate : $v_c = 1152$ m/min

Advance per rotation : $f_t = 0.25$ mm/r

Cutting depth : $a_p = 2.54$ mm

Lubricant : emulsion . .

Experiment No.	Layer	Working Cycles	Cycle Average
10	TiN	15.0	14.8
11		13.0	
12		15.5	
13		15.5	
14	TiAlN "A"	37.0	24.8
15		19.0	
16		21.5	
17		21.5	
18	TiAlN "B"	13.0	12
19		11.0	
20		12.0	
21		12.0	

Example 3

Tool : HSS drill, 6 mm
Material worked : AISI D3 = DIN 1.2080
Cutting rate : $v_c = 35$ m/min
Advance per rotation : $f_0 = 0.12$ mm/r
Engagement size : $a_e = 3$ mm
Drilling depth : $h = 15$ mm, pocket hole
Lubricant : 5% emulsion

Experiment No.	Layer	Average Number of Holes
28	TiN	45
29	TiCN	85
30	TiAlN "A"	190
31	TiAlN "B"	30

Examples 1, 2 and 3 show that for specific tools and conditions of use a composition of the hard material changed in the active edge region, in particular depletion of Al, leads to markedly poorer service lives than an unchanged composition of the hard material layer.

Example 4a

Tool : Hard metal roughing shank-type milling cutter, $\phi = 10$ mm, 25/64
Teeth number : $z = 4$
Material worked : DIN 1.2344, 55-56 HRC
Cutting rate : $v_c = 50$ m/min

Advance per rotation : $f_t = 0.02$ mm/tooth
 Engagement size : $a_e = 2$ mm
 Cutting depth : $a_p = 10$ mm
 Lubricant : dry, compressed-air cooling

Experiment No.	Layer	Wear Width in μ m after x Operations			
		x = 10	x = 20	x = 30	x = 35
22	TiAlN "A"	45	54	65	70
23	TiAlN "B"	50	69	80	88

This example shows especially hard conditions of use since hard material is worked dry. The tools coated with the parameters A and consequently tools with unchanged composition of the hard material layers in the active edge region show markedly lower wear mark widths than tools with changed composition of the hard material layer in the active edge region.

Example 4b

Tool : Hard metal roughing shank-type milling cutter,
 $\phi = 10$ mm, 25/64

Teeth number : $z = 3$
 Machined material : DIN 1.2311, 33 HRC, $R_m = 1050$ N/mm²
 Cutting rate : $v_c = 100$ m/min
 Advance per rotation : $f_t = 0.035$ mm/tooth
 Engagement size : $a_e = 3$ mm
 Cutting depth : $a_p = 16$ mm
 Lubricant : 5 % emulsion

Experiment No.	Layer	Average Length of Path
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24	TiN	24
25	TiCN	27
26	TiAlN "A"	42
27	TiAlN "B"	78

This example makes evident that at high cutting rate and additional emulsion lubrication, further with relatively soft material to be worked, on average greater path lengths are achieved with the coating technique according to B.

Consequently, Examples 4a and 4b show that in similar operations but different conditions of use, identical tools coated differently in the active edge region are advantageous in each instance.

In the following Examples 5 to 9 further tools are specified with the particular applicable coating parameters analogous to A and B. Those tools with constant composition of the hard material layer in the active edge region are denoted by A_0 , analogous tools with changed composition of the hard material layer in the active edge region by B_0 . Apart from the specified coating parameters, identical basic tool bodies were coated with identical coating processes and compared with one another with respect to their service life.

Example 5

Tool : milling cutter with indexable inserts SEE 42 TN (G9)

Teeth number : $z = 6$

Layer thickness $(Ti_xAl_y)N$: each 4.5 μm

Material worked : SKD 61 (HRC45)
 Cutting rate : $v_c = 100$ m/min
 Advance per tooth : $f_z = 0.1$ mm/tooth
 Cutting depth : $a_p = 2$ mm

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Cutting length [m]
		Bias [-V]	N2 [10 ⁻² mbars]	Arc Current [A]		
A ₀	32	60	2.5	150	1	3.2
	33	60	3.2	150	1	3.0
	34	40	2.0	150	0	8.8
	35	40	4.0	150	0	3.9
	36	40	0.5	150	0	2.0
	37	30	2.0	150	0	4.2
B ₀	38	100	2.0	150	4	1.1
	39	150	3.0	150	7	1.1
	40	150	2.0	150	4	0.5

Example 6

Tool : HSS drill, ϕ 6 mm
 Layer thickness (Ti_xAl_y)N : each 5 μ m
 Intermediate TiN layer : each 0.5 μ m
 Material worked (with emulsion) : DIN 1.2080 (AISI D3)
 Cutting rate : $v_c = 40$ m/min
 Advance : $f = 0.10$ mm/r
 Drilling depth : 15 mm (pocket hole)

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Number boreholes
		Bias [-V]	N2 [10 ⁻³ mbars]	Arc Current [A]		
A ₀	41	40	3.0	200	0	198
	42	40	3.0	200	0	231

B ₀	43	150	1.0	200	7	45
	44	150	1.0	200	7	38

Example 7

Tool : HSS roughing milling cutter, ϕ 12 mm
 Number of teeth : $z = 4$
 Layer thickness (Ti_xAl_y)N : each 4.5 μ m
 Intermediate TiN layer : each 0.3 μ m
 Material worked dry : DIN 1.2344 (AISI H13)
 Cutting rate : $v_c = 120$ m/min
 Advance per tooth : $F_z = 0.6$ mm/tooth
 Cutting depth : $a_p = 20$ mm
 Engagement size : $a_e = 5$ mm

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Cutting length [m]
		Bias [-V]	N2 [10 ⁻² mbars]	Arc Current [A]		
A ₀	45	40	2.5	200	0	41
B ₀	46	150	1.0	200	7	12

Example 8

Tool : Hard metal drill, ϕ 11.8 mm
 Layer thickness (Ti_xAl_y)N : each 5 μ m
 Intermediate TiN layer : each 0.5 μ m

Material worked
(with emulsion) : GG 25 (gray cast iron)
Cutting rate : $v_c = 110$ m/min
Advance : $f = 0.4$ mm/r
Drilling depth : 35 mm (pocket hole)

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Number boreholes
		Bias [-V]	N2 [10 ⁻² mbars]	Arc Current [A]		
A ₀	47	40	3.0	200	0	2840
B ₀	48	150	1.1	200	7	1270

Example 9

Tool : Hard metal indexable insert, external turning
Layer thickness ($\text{Ti}_x\text{Al}_y\text{N}$) : each 5 μm
Intermediate TiN layer : each 0.2 μm
Material worked
(with lubrication) : DIN 1.4306 (X2CrNi 1911)
Cutting rate : $v_c = 240$ m/min
Advance per rotation: $f = 0.6$ mm
Cutting depth : $a_p = 1.5$ mm

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Cutting length [m]
		Bias [-V]	N2 [10^{-2} mbars]	Arc Current [A]		
A ₀	49	40	3.0	200	0	4.732
B ₀	50	150	1.0	200	7	2.015

The Examples 5 to 9 show the superiority of tools with unchanged hard material layer composition in the active edge region in different specific applications.

Example 10

Tool : Hard metal front-end milling cutter, ϕ 10 mm
 Tooth number : $z = 6$
 Layer thickness $(Ti_xAl_y)N$: each 3.5 μm
 Material worked dry AISI (DIN 1.2379), 60 HRC
 Cutting rate : $v_c = 20$ m/min
 Advance per tooth : $f_z = 0.035$ mm/tooth
 Cutting depth : $a_p = 15$ mm
 Engagement size : $a_e = 1$ mm

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Cutting length [m]
		Bias [-V]	N2 [10^{-2} mbars]	Arc Current [A]		
A ₀	51	40	3.0	200	0	4
	52	40	2.0	200	0	2
	53	20	2.0	200	0	3
	54	70	3.0	200	1.5	12
B ₀	55	200	3.0	200	9	21
	56	150	2.0	200	7	29
	57	100	1.0	200	4	17
	58	100	2.0	200	4	22

Example 11

Tool : Hard metal front-end milling cutter, ϕ 10 mm
 Tooth number : $z = 6$
 Layer thickness $(Ti_xAl_y)N$: each 3.5 μm
 Intermediate TiN layer : each 0.1 μm
 Material worked DIN 1.2379 (AISI D2), 60 HRC
 Cutting rate : $v_c = 20$ m/min
 Advance per tooth : $f_z = 0.03$ mm/tooth
 Cutting depth : $a_p = 15$ mm

Engagement size :

 $a_e = 1 \text{ mm}$

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Cutting length [m]
		Bias [-V]	N2 [10 ⁻² mbars]	Arc Current [A]		
A ₀	55	40	3.5	200	0	22
B ₀	56	150	1.0	200	7	31

Example 12

Tool : Hard metal ball-end milling cutter J97 (Jabro), R4 (ø 8 x 65 mm)

Layer thickness (Ti_xAl_y)N : each 3.5 µm

Intermediate TiN layer : each 0.1 µm

Material worked dry : DIN 1.2343, 49.5 HRC

Cutting rate : $v_c = 240 \text{ m/min}$

Cutting depth : $a_p = 0.5 \text{ mm}$

Samples	No.	Coating Conditions			Al decrease toward edge [at%]	Cutting length [m]
		Bias [-V]	N2 [10 ⁻² mbars]	Arc Current [A]		
A ₀	57	40	3.0	200	0	111
B ₀	58	150	1.0	200	7	168

Examples 10 to 12 show that under certain application conditions and with specific tools the service lives are increased if the composition of the hard metal layer is changed in the active edge region.